Federal Communications Commission
International Bureau
Washington, DC 20554

February 3, 2005

Via Electronic Filing
Ms. Marlene H. Dortch, Secretary
Federal Communications Commission
445 12th St., S.W.
Washington, DC 20554

Re: *Ex Parte* Presentation
IB Docket No. 01-185

Dear Ms. Dortch:

On Wednesday, February 2, 2005, I attended a meeting convened by the Department of Defense, which included representatives of the Department of Defense, the National Telecommunications and Information Administration, Mobile Satellite Ventures LP ("MSV"), and Inmarsat Ventures Limited ("Inmarsat") regarding several issues that have been raised in this proceeding. My role in this meeting was that of observer and technical resource on prior Commission decisions in this proceeding. A list of the attendees is contained in Appendix A.

The meeting attendees discussed a number of topics, including third-order intermodulation interference to MSS receivers from ATC base station operations; potential interference to land-based MSS terminals including operational considerations; single station and aggregate interference to aeronautical MSS receivers from ATC base stations; interference thresholds in MSS receivers; and uplink interference from MSS/ATC handsets to Inmarsat MSS satellites. Much of the information discussed has already been presented in the record of this proceeding. However, Inmarsat did provide and present portions of a presentation titled "ATC Impact on DoD MSS Capability," a copy of which is contained in Appendix B. Inmarsat also mentioned that the forward error correction in their system had a relatively small range of variability, and that it was not suitable to overcome the effects of ATC interference.

Inmarsat clarified that most commercial aircraft operators choose receivers that are designed to satisfy ARINC Characteristic 741 because they desire equipment that is designed to be interoperable with other aeronautical equipment. However, almost all other aeronautical receivers are designed to satisfy RTCA DO-210. In discussing the threshold to use in studying aeronautical receiver overload, Inmarsat referred to a 1994 letter from Orville K. Nyhus, PhD, of Honeywell, Inc., that was used to establish a value of -72 dBm contained in RTCA DO-210D which has been previously discussed in the record of this proceeding. A copy of that letter is attached in Appendix C.

Inmarsat also indicated that most Inmarsat receiver installations aboard aircraft would have antennas placed on each side of the aircraft, slightly above the horizontal center line. As such, Inmarsat did not agree that there would be a 10 dB blocking factor that would apply when calculating the anticipated signal level from an ATC base station into the aircraft's MSS receiver. The Inmarsat receiver would use the antenna that had the strongest Inmarsat satellite signal.

MSV made reference to empirical studies it has conducted with assistance from LCC International, Inc. and Qualcomm which demonstrate, according to MSV, that the average output power of a mobile terminal operating on an ATC system using existing cellular/PCS towers will be roughly 10 dB less than predicted by the model the FCC developed in the 2003 ATC Order. MSV indicated that the study is available on its website (www.msvlp.com). MSV indicated that it anticipates that its ATC base stations would be established in densely populated areas covering a small percentage of the U.S. land mass. MSV also indicated that its MSS/ATC handsets will use the same power level to transmit to ATC base stations and MSS satellites, around -7 dBW for CDMA modulation, with a 10-14 dB link margin. MSV also indicated that the power in the uplink band generated by all of its ATC operations in a city would typically not exceed the power generated by a current MSV mobile earth terminal in the same band.

The views of DoD and NTIA representatives were still being formulated, and will be submitted to the Commission by next Tuesday.

/s/

Richard B. Engelman
Chief Engineer
Federal Communications Commission
International Bureau

Attachments (3)

Appendix A

List of Meeting Participants

Name	Organization	Email Address
Richard Engelman	FCC	Richard.Engelman@fcc.gov
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Appendix B

ATC Impact on DoD MSS Capability

Presentation to NII

2 February 2005

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Agenda

- Purpose
- Executive summary
- Impact on aeronautical terminals
- Impact on land, maritime terminals
- Impact on Inmarsat 4 satellites
- Conclusion

Why are we here?

Unless the DoD acts immediately, relaxation of the 2003 ATC Rules will seriously jeopardise the DoD's use of Inmarsat services.

Overview

Radiation from ATC base stations as licensed will interfere with aircraft and helicopter communications up to 4,500m in altitude and up to 40,000m in horizontal distance from the base stations.

ATC base stations as licensed will interfere with current and future Inmarsat land and maritime MSS terminals, creating "exclusion zones" up to 3,000m in diameter around large numbers of base stations.

Transmit signals from large numbers of ATC terminals (as licensed) in the aggregate, will overwhelm the receivers on Inmarsat MSS satellites.

Interference from ATC, as licensed, will interrupt or preclude Inmarsat communications, undermining the "always available" function played by these links for critical government communications in the air, on land, and at sea.

Technical limits must be set in the ATC rules that ensure the security of government communications via Inmarsat.

Executive Summary

History

- After two years of extensive studies and debate, the FCC issued the **ATC Order** in Feb-03. The Order reflected a balance between encouraging a new technology whilst protecting existing MSS services
- Even though the Order incorporated most of MSV's earlier requirements, MSV immediately proposed a multitude of significant relaxations of ATC limits following the release of the Feb-03 Order
- In Nov-04, the FCC International Bureau issued the **MSV Licence Order** granting some significant relaxations requested by MSV
- Further MSV proposals are expected to be addressed in an imminent FCC Order

Downlink Interference – Aero, Maritime, Land

- MSS terminals have been designed for an interference environment in which the MSS band is exclusive for MSS
- Receivers of MSS terminals must necessarily have high sensitivity
- Receivers rely on low noise components and reasonably interference free environment to demodulate extremely weak signals from space
- MSS terminals can’t benefit from power control features to combat interference, common in terrestrial cellular system
- The resulting interference will prevent many MSS terminals from operating in large areas around ATC Base Stations

The Aeronautical Terminal Problem

- MSV License Order granted with relaxations of EIRP limits, pfd limits and distance limits on ATC base stations
  - This was based on an incorrect AMSS receiver sensitivity assumption, a 22dB error according to the FAAs' AMSS requirements
  - 8-10 dB relaxation was granted to base station overhead antenna gain suppression
  - 8 dB increase in transmit (EIRP) limit for base stations

- Further relaxations are being considered, beyond those already granted

The Aeronautical Terminal Problem

- At any given time, hundreds of aircraft are relying on AMSS to communicate, whether on the ground or in the air
- High penetration of AMSS into the DoD, Air Command, and US government fleet of 747s, 757s, Gulfstreams, C13Os, C40s, P3s, VC9s, E4s, GAH-64D Apaches, etc.
- U.S.' Presidential fleet also highly dependent on a highly reliable service for critical communications
- Over 70% fit of AMSS in U.S. and foreign aircraft on long-hauls flights departing/arriving and over 90% fit of AMSS in the top-end corporate aircraft

The Land and Maritime Terminal Problem

A variant of the aeronautical problem

Three crucial interrelated issues:

- Receiver sensitivity/interference threshold
  - MSV License order uses -60 dBm threshold; should be -75 dBm
  - BGAN terminals are being introduced which have not been considered by the FCC
- FCC assumes negligible MSS use anywhere near ATC base stations
- ATC base station EIRP increase results in a proportional increase in the area of the exclusion zone

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The Satellite Problem

The uplink interference issue. Two elements:

- Co-channel interference from ATC handsets into MSS satellites using the same frequencies in other geographical areas
- Saturation of the A/D converters at the input of Digital Signal Processors of Inmarsat 4 satellites covering the same geographical areas

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The Uplink Interference Environment - Satellite

- Uplink interference produced by ATC handsets into MSS satellites. The two most important interference mechanisms are:
  - Co-channel interference from ATC handsets into MSS satellites using the same frequency in other geographical areas
  - Saturation of the A/D converters at the input of Digital Signal Processors of Inmarsat 4 satellites covering the same geographical areas

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The Aeronautical Problem

ATC Base Station Interference

- Aeronautical terminals have been designed for the interference environment which prevails in the MSS band
- AMSS receivers must be designed with high sensitivity and low noise components to demodulate extremely weak signals from space
- Satellite power control is not capable of being used to counter interference, as is feasible in many terrestrial cellular systems
- ATC base stations, as licensed, will interfere with AMSS terminals

Interference to Aeronautical Terminals

- **Problem 1:**
  - The ATC Order did not incorporate the correct mandatory specification for AMSS receiver sensitivity, as is used by the large majority of today's aircraft. As a result, the Order incorporates a 22dB calculation error
    - ATC Order is based on the incorrect interpretation of the receiver LNA compression point from the <u>'voluntary'</u> ARINC Characteristics 741
    - RTCA DO-210D, Minimum Operational Performance Standards (MOPS) is the only <u>'mandatory'</u> standard for AMSS and AMS(R)S services
    - FAA's Technical Standard Order (TSO) C-132 for AMSS equipment refers exclusively to RTCA DO-210

Interrelationship Between AMSS Standards

ICAO Standards and Recommended Practices, Annex 10 to the 'Chicago Convention'

ICAO SARPS

RTCA MOPS DO-210D

US National Minimum Requirements for AMSS to comply with SARPs as promulgated by ICAO

ARINC Characteristics 741

Voluntary characteristics for form, fit and function for AMSS avionics. Primarily to foster avionics interoperability between different suppliers and to allow pre-wiring of aircraft

Inmarsat SDM

Inmarsat mandatory requirements for AMSS equipment to receive approval for access to Inmarsat's Aeronautical Services

FAA's TSO C-132

FAA's mandatory technical standard for AMSS equipment, which refers back to RTCA 210D for minimum performance requirements

Interference to Aeronautical Terminals

- **Problem 2:**

The two areas of relaxation granted to MSV (EIRP and overhead gain) total 16–18 dB degradation

The relaxations granted to MSV will result in aircraft losing AMSS communications within distances of up to 40km of a Base Station and up to altitudes of 4,500m

DoD aircraft will operate within these distances from ATC networks

Further relaxations under consideration would make this problem even worse

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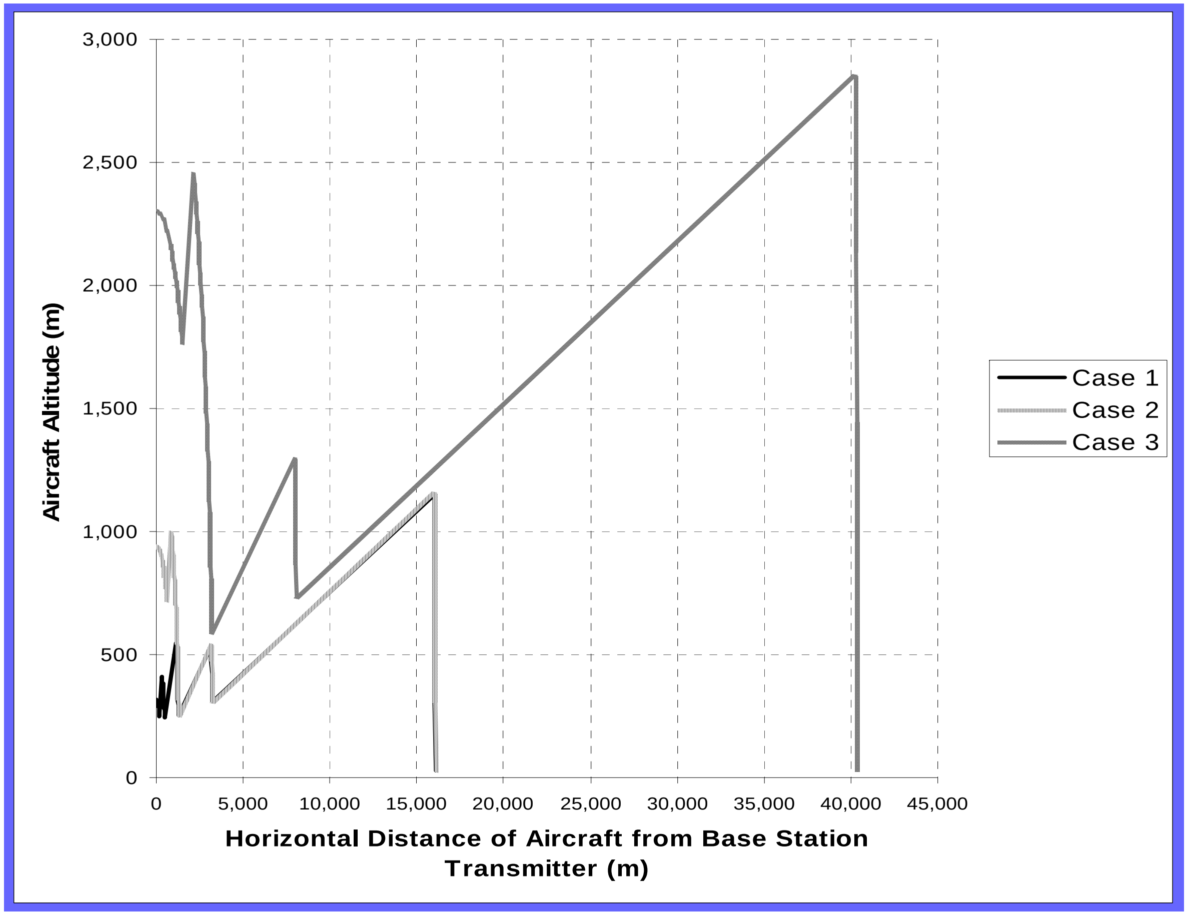
The Aeronautical Terminal Problem

Safe Distance of an Aircraft from an ATC Base Station Resulting from MSV License (one sector, no PC, no VA)



Case 1: Original ATC Rules

Case 2: ATC gain suppression reduced by 8-10 dB

Case 3: ATC gain suppression reduced by 8-10 dB *and* Base Station EIRP is relaxed by 8 dB

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Interference to Aeronautical Terminals

- Aircraft flying 900m or less above an ATC base station will suffer receiver saturation
- Interference altitudes increase at lower elevation angles of the aircraft to the ATC base station
- More realistic assumptions dramatically increase these distances

- Demonstration
  - ATC base station peak EIRP per sector = +32 dBW
    (i.e., 8 dB increase over the value in the ATC rules)
  - Gain suppression towards aircraft (at zenith) = 30 dB
    (i.e., using the relaxed overhead gain suppression mask)
  - Therefore ATC base station EIRP per sector towards aircraft = +2 dBW
  - Distance between ATC base station antenna and aircraft at zenith = 870 meters
    (i.e., 900 meters altitude less ATC antenna height of 30 m)
  - Spreading loss from ATC base station antenna to aircraft = 10 log (4 p 8702) = 69.8 dB
  - Effective aperture of 0 dBi receive antenna at 1.5 GHz
    = G l2 / 4 p = 0.003183 m2 = –25.0 dB-m2
  - Interfering signal power at Inmarsat receiver (per sector)
    = +2 – 69.8 – 25.0 – 4 (voice activity) – 5.2 (power control) = –102 dBW = –72 dBm (threshold)

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Interference to Aeronautical Terminals

- Other factors could increase interference by up to 14dB
  - Multiple antenna sectors of single ATC base station (4.8 dB worse for 3 sectors)
  - Single base station so no power control averaging (5.2 dB worse)
  - Data transmission so no voice activity factor (4 dB worse)
  - Plus no limit in the number of carriers per ATC base stations
- When flying over an ATC base station, receiver saturation could occur at 4,490m
- The impact of multiple base stations further compounds the problem

Interference to Aeronautical Terminals

- Over CONUS, at any given time, hundreds of aircraft are relying on AMSS to communicate, whether on the ground or in the air
- Over 70% fit of AMSS in US and foreign aircraft on long-hauls flights departing/arriving
- Over 90% fit of AMSS in the top-end corporate aircraft (Gulfstream, Challenger, Falcon, Boeing Business Jet, etc)
- High penetration of AMSS into the DoD, Air Command, and US government fleet of aircraft operating over CONUS and elsewhere
- US' Presidential fleet of aircraft also highly dependent on AMSS
- This is an important security issue as the availability levels of AMSS communications are necessarily very high

The Land and Maritime Terminal Problem

The Downlink Interference Environment

- Downlink interference will be produced by ATC base stations into Inmarsat Mobile Earth Terminals (MET). The two most important interference mechanisms are:
  - Co-channel interference produced by IM products of carriers transmitted by the base stations
  - Saturation of the front-end of Inmarsat MET's due to the huge power level difference between the satellite and base station signals

Downlink Issues – MSV Licence Order

- In the MSV License Order
  - ATC base station EIRP limit has been relaxed by 8 dB
  - The limit on the number of ATC carriers per base station has been waived

- The EIRP relaxation is not based on any evidence of reduced sensitivity to interference of Inmarsat terminals. This will lead to increased areas around ATC base stations where Inmarsat service is unavailable

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MSS service areas overlap ATC service areas

- Inmarsat's land METs will certainly be operated near ATC base stations
  - BGAN is a revolutionary new service that relies on ubiquitous service where an Inmarsat satellite can be accessed
  - Special users (e.g., homeland security, safety services, government, military) require <u>absolute certainty</u> that Inmarsat service is available – cannot tolerate black holes in coverage

- ATC base stations are to be widely deployed
  - MSV has stated that it desires to employ as many existing cellular base station sites as possible for deployment of its ATC base station hardware
  - Economics of satellite vs terrestrial spectrum efficiency will dictate that MSV use ATC in preference to satellite except in the most remote areas
  - Nothing in FCC rules prevents or discourages MSV from deploying ATC base stations well into suburban areas

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ATC base station EIRP relaxation

- The calculated interference regions are determined by the EIRP levels, the number of base stations employed and the terminal threshold levels
- The FCC assumes an interference threshold of –60 dBm for land and maritime terminals; Inmarsat terminal manufacturers have measured the interference threshold as –75 dBm
- The 8 dB EIRP relaxation and the correct Inmarsat Rx threshold of -75 dBm would result in the separation distances of >3,000 meters
- Line-of-sight propagation conditions will exist around many ATC base stations, and must be taken into account
- These exclusion zones will exist around potentially tens of thousands of ATC base stations, and will greatly constrain the areas where the DoD can use Inmarsat services

Interference to Maritime Terminals

- Concerns with Maritime services have largely been addressed by the FCC. Increased base station EIRP levels have been compensated for by increasing the distance from waterways to an ATC base station
- The one outstanding concern on Maritime services is associated with the 15 dB discrepancy between the FCC analysis and the Inmarsat terminal manufacturers for Rx threshold sensitivity levels
- The result of such interference will manifest itself in the form of MSS service availability gaps around the US coastline and in waterways around the country

The Satellite Problem

Co-channel Uplink Interference

The Satellite Uplink Interference Problem

- A population of active ATC mobile terminals will create uplink co-channel interference into Inmarsat satellites
- The MSV License Order allows a significant increase in uplink co-channel interference through increased number of reuses and increased interference levels per MT
- MSV proposals for additional relaxations would result in interference levels that by far exceed the entire interference allowance in Inmarsat link budgets and render Inmarsat services unavailable in large geographic regions

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Problems

- MSS services need to be designed to operate with a tight interference margin
- ATC brings unforeseen, and hence unbudgeted interference that must therefore be kept to a minimum
- Increased uplink interference would impact all users, in all theatres of operation, who are relying on access to the interfered satellite
- ATC interference analysis assumes that the average MT EIRP will be 20 dB below maximum. However, no mechanism is in place to ensure this will happen
- Underestimation of spatially averaged maximum EIRP towards satellite
- Other factors in FCC analysis also underestimate interference impact

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Average MT EIRP

- A key assumption in the 2003 FCC analysis is that there will be 20 dB interference reduction due to power control

i. The relaxed interpretation of the structural attenuation requirement in the MSV license Order does not ensure that the 20 dB factor is valid

ii. MSV’s proposed method of achieving sharp signal cut-off at edge of ATC coverage will not work

iii. MSV’s example ATC link budget leads to -17.5 dBW average MT EIRP for outdoor mobiles, i.e. 2.5 dB higher than required

iv. Shortcomings in the MSV ATC link budget mean that ATC MTs are likely to operate at 6 dB higher power levels than assumed

v. Fast moving mobiles will not always be served by the strongest cell, resulting in increased average MT EIRP

IB Interpretation of structural attenuation margin

- IB found that MSV has met the requirement to “demonstrate that the cellular structure of the ATC network design includes 18 dB of link margin allocated for structural attenuation” [§25.253 (a) (8)]
- IB interpreted this rule to mean that ATC licensees should not extend a base station’s coverage beyond the point where an MT would have to transmit more than –18 dBW to overcome free-space loss [MSV Order at 32]
- This interpretation allows MSV to flout the requirement to keep average ATC MT at least 20 dB below maximum

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Sharp Signal Cut-off at Edge of Coverage

- To achieve an average EIRP that is 20 dB below maximum, MSV has to prevent MTs from operating at high power levels outside the ATC coverage area
- MSV's method of having receive-only cells at edge of coverage will not achieve this
- The edge of coverage is likely to be a complex shape
- There are other scenarios where MTs will receive usable signals from far away base stations

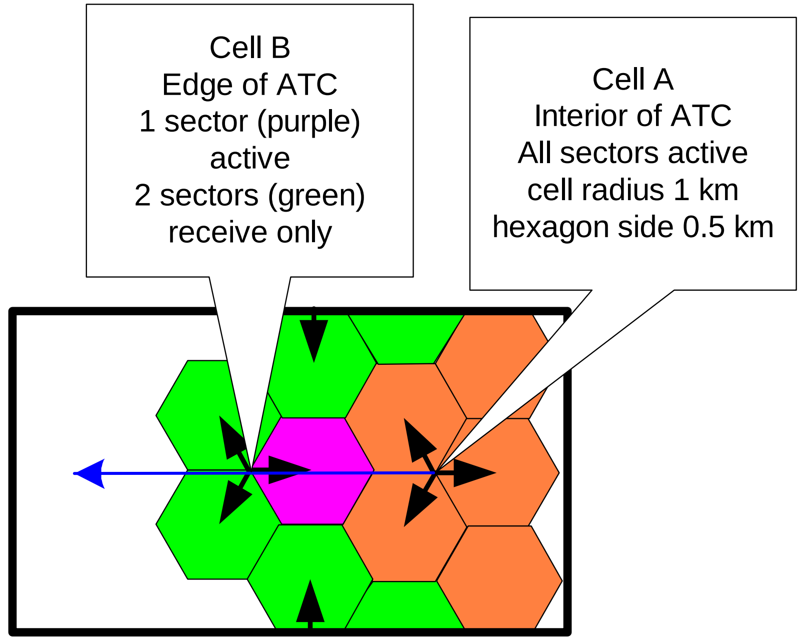

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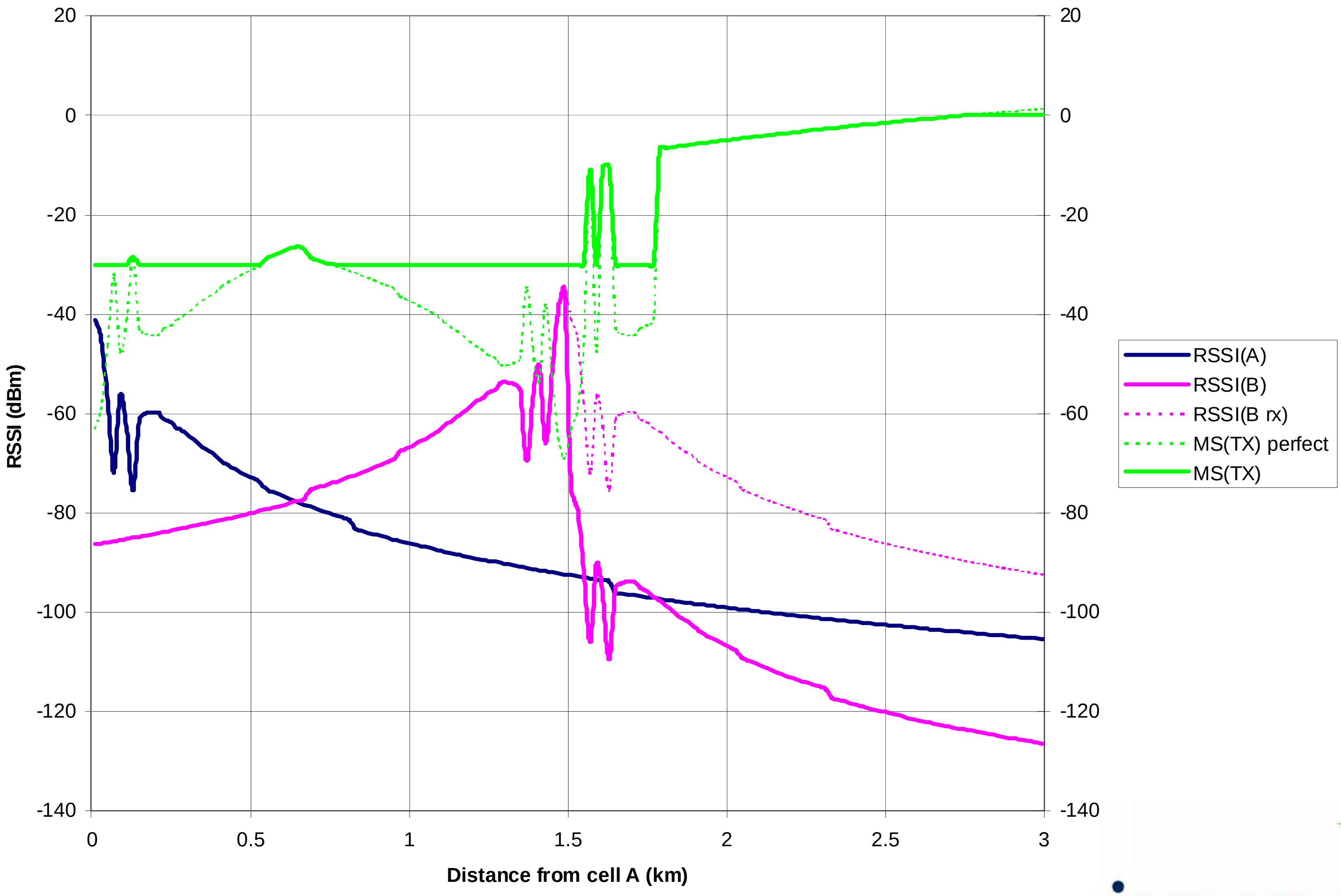
Illustration of cell handover dynamics



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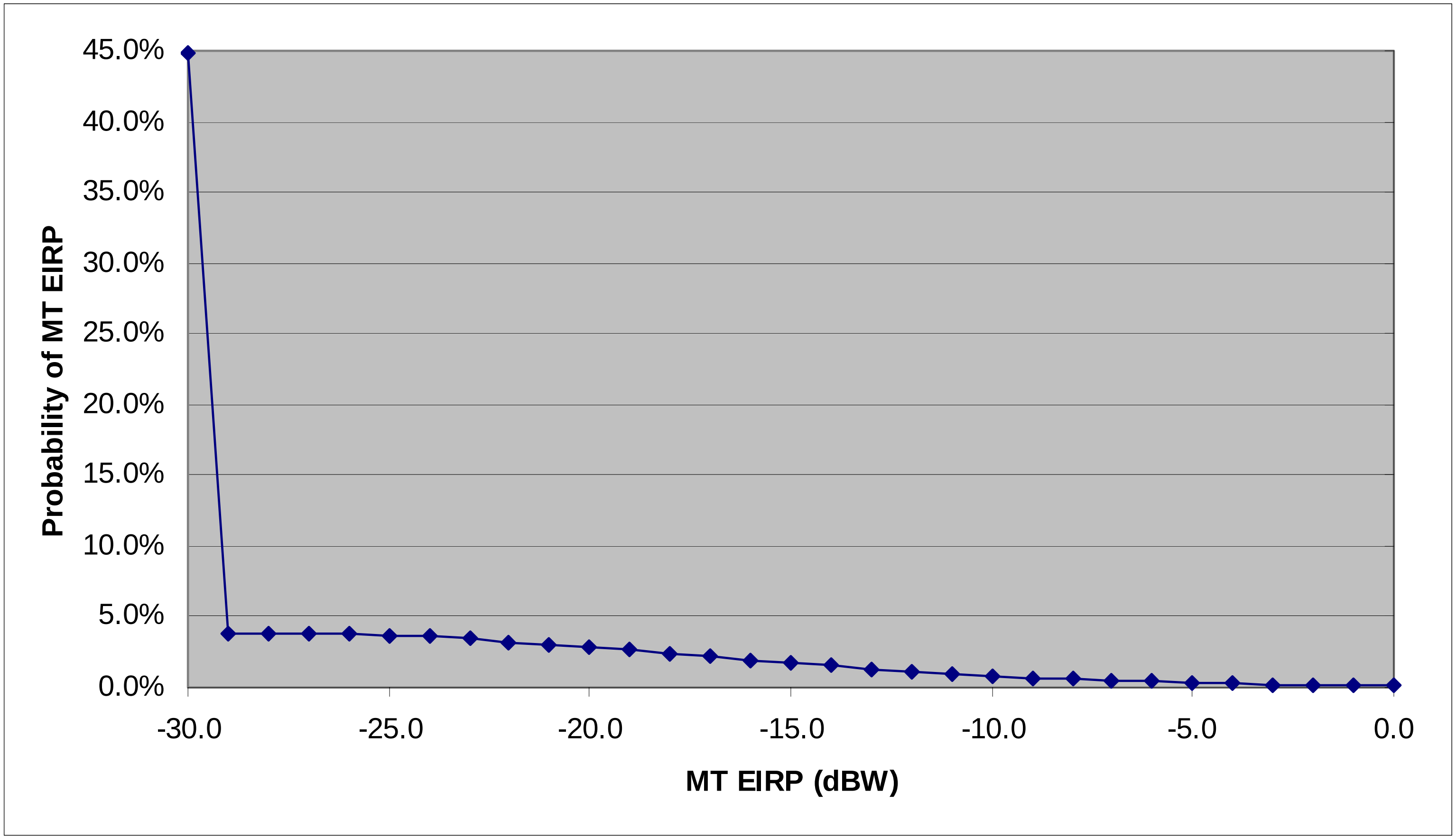
Distribution of MT EIRP Based on MSV Link Budget



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MSV ATC Link Budget

- MSV ATC link budget assumes a base station sensitivity of –110 dBm, 6 dB below specification
  - 3 dB improvement realistic
- Link budget does not include uplink interference margin
  - 3 dB is typically needed
- As a result, there is a link imbalance, so that the maximum path loss is greater in the downlink than in the uplink
- MSV would need higher MT EIRP levels than assumed in their link budget
- Relaxations of the base station EIRP limits would leave MSV with excess downlink power

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Fast Moving Mobile Terminals

- Delay between the ideal handover point and actual handover
- A fast moving mobile can travel a significant distance during this delay
- As a result, the MT will not always be served by the strongest base station and the power control will not work as assumed
- Handover hysteresis will result in similar effects to the above

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Average MT EIRP Towards Satellite

- MSV measurements show that the average MT antenna gain is –4 dBi, resulting in a spatially averaged maximum MT EIRP towards the ATC base station 4 dB below peak
- The IB assumed that the average MT EIRP towards the satellite will also be 4 dB below peak – this is incorrect
  - $E\{EIRPsat\} = E\{EIRP\}base*E\{G\}*E\{1/G\}$
- Average EIRP towards the satellite is 4.5 dB higher than the average EIRP towards the ATC base station
  - Assuming that the gain is a sine function with 15 dB nulls, the average gain is –3 dB and average inverse gain is 7.5 dB

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Other Factors That Underestimate Interference

- The following factors in the Commission's interference analysis **underestimate** the interference to Inmarsat:
  - Inmarsat satellite location: I4 operation at 98W would increase interference to Inmarsat by 3 dB compared with 54W as assumed by the FCC
  - Inmarsat satellite antenna discrimination: 25 dB isolation assumed by the FCC – this could be lower depending on frequency coordination
  - Inmarsat satellite G/T: 12.87 dB/K assumed by the FCC is a worst case value – most beams will have G/T values up to 1.5 dB higher
- The 41 dBi MSV satellite antenna gain used in the Feb-03 analysis is incorrect – using the correct gain of 42.5 dBi, as declared by MSV, would necessitate a reduction in the number of co-channel reuses to maintain protection of the MSV satellite

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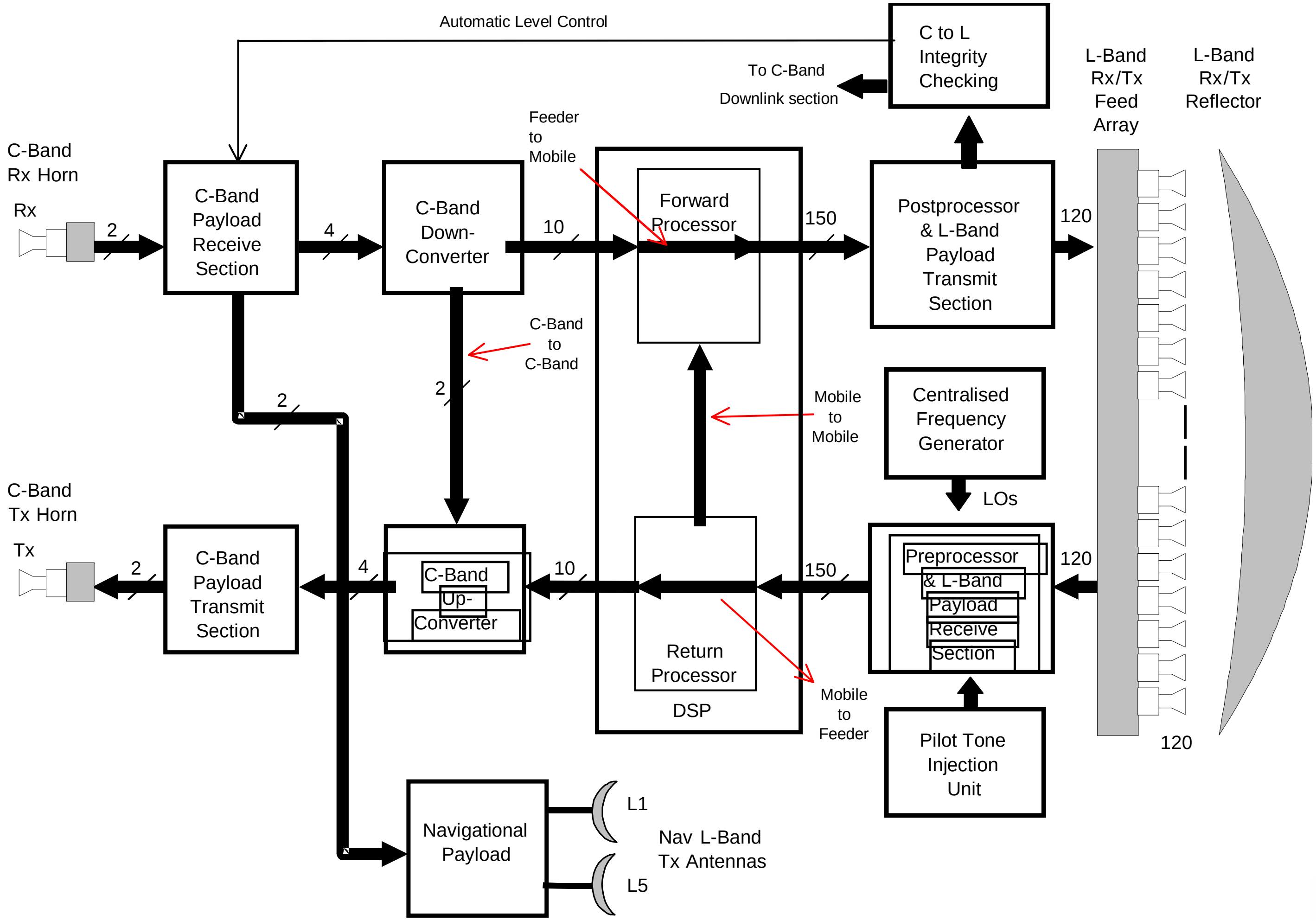
Inmarsat A/D Converter Saturation

The Inmarsat 4 Payload



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Impairment Mechanism

- The path for an interfering signal at the input of one of the 120 feed elements leads through dedicated LNA, filtering and down-conversion chains, to an A/D converter at the input of the DSP.
- The A/D converters and signal levels were set to provide adequate S/N for a range of different services
- The User Link G/T specifications assumed a maximum combined interference level of 40 dBW EIRP spread over 34 MHz.
- Problem is geographically based. Users within the coverage of the impacted element would see a lower G/T or, depending on the interference level, be jammed and unable to communicate
- Exact impairment assessment is not trivial, as it depends on ATC user distribution and power levels toward the satellite

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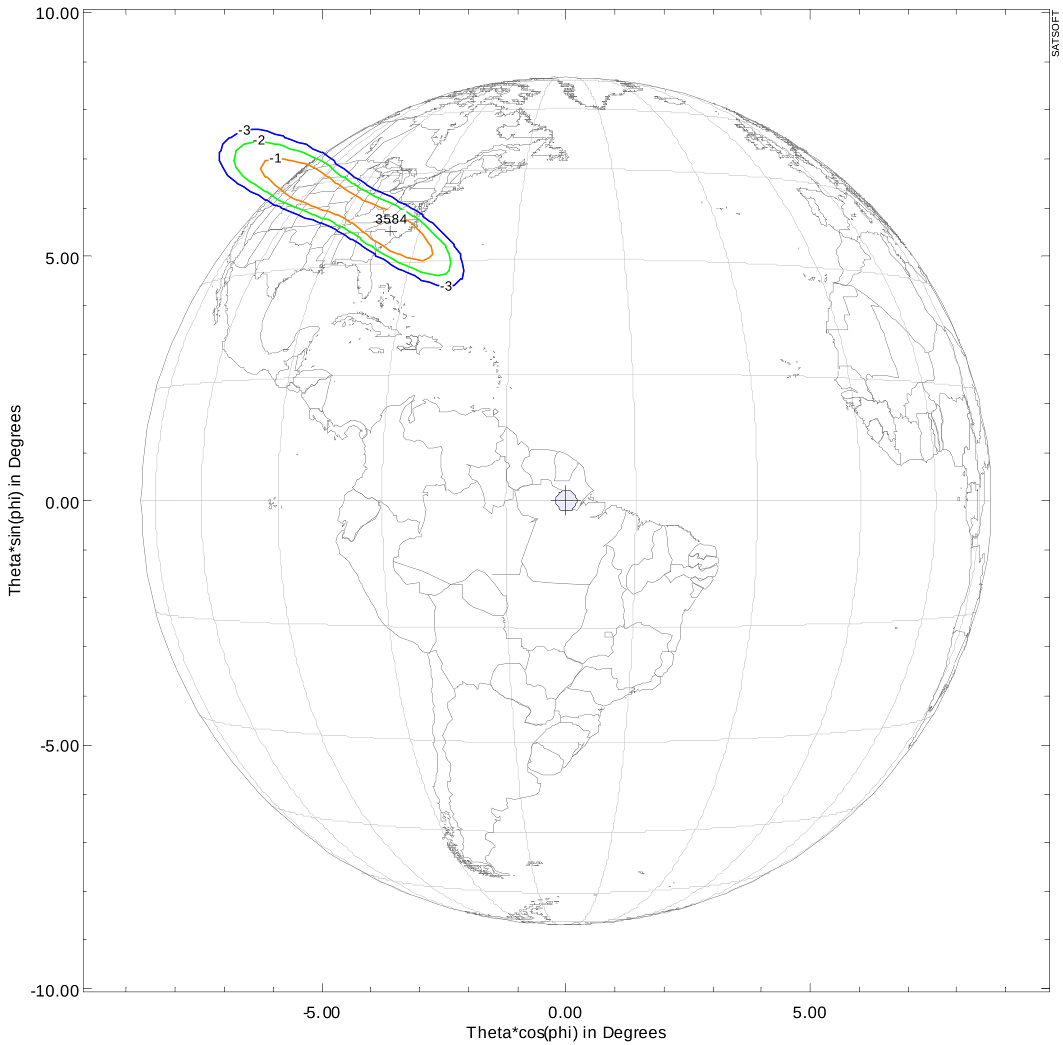
Typical Element Coverage (Element 89)



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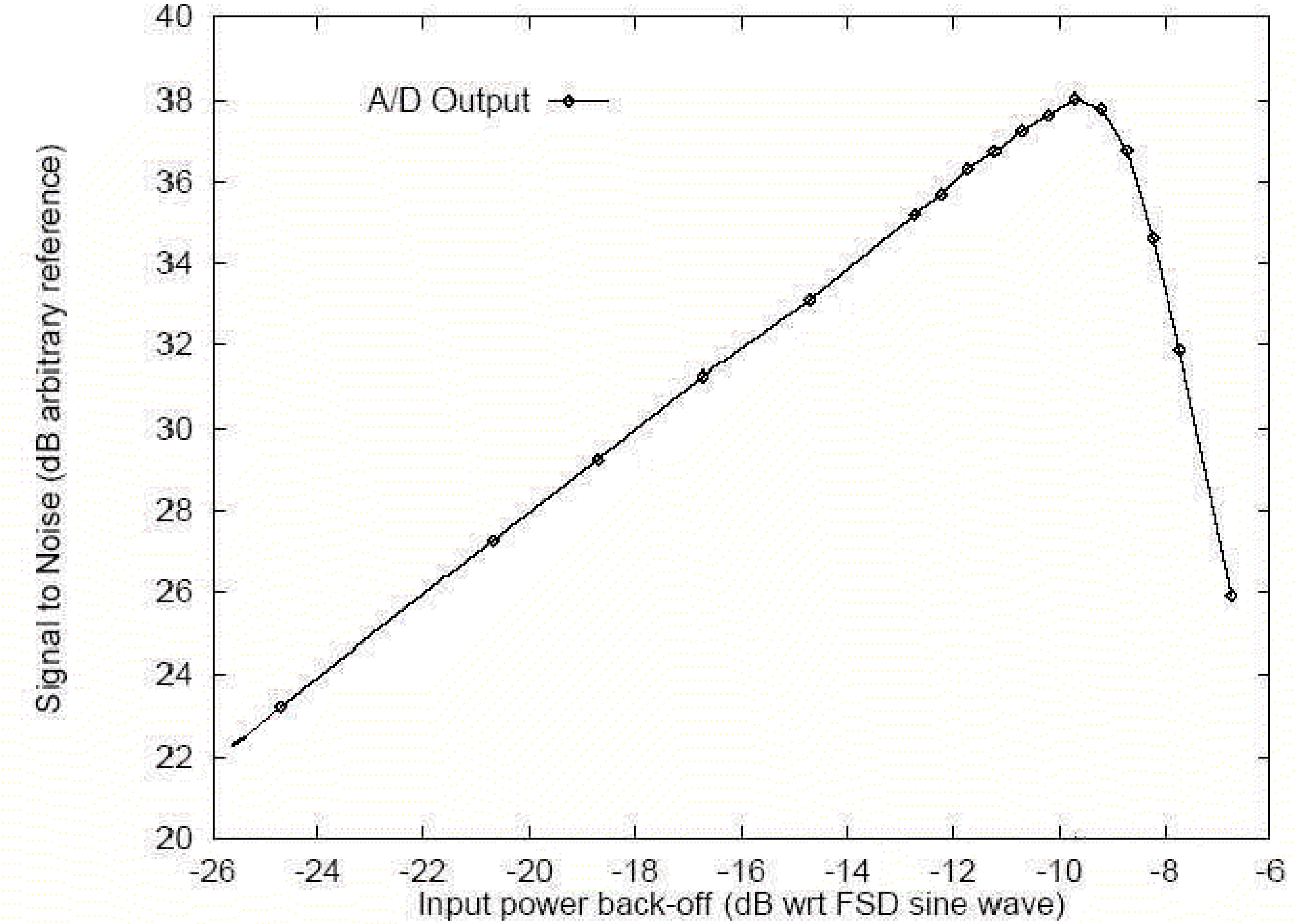
A/D Typical S/N Response



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Example Calculation

- The manufacturer designs the payload so that the expected wanted signal and interference levels drive the ADC very close to the maximum S/N point
- The specs call for a total aggregate interfering EIRP of 40 dBW, referred to the edge of the earth and on the element -3 dB gain contour. As follows:
  - 37 dBW interference from Inmarsat services using other satellites
  - 35.7 dBW for interference from other MSS systems
  - 31 dBW for ATC interference
- Assuming -20 dBW average ATC user EIRP, located on average 1 dB below the element peak gain and with path loss 0.5 dB below that at the edge of the earth we get a maximum of 70k users allowed in the area of one element
- Unproven interference reduction factors (polarisation, obstruction, voice activation and vocoder) totalling 3.9 dB could take that to 170k users
- ATC order would allow 85K users (GSM & 1725 re-uses in 10 MHz), MSV requested relaxation would result in a maximum of 1.5M users

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Conclusion

Mobile Satellite Users Association:

"ATC is, of course, an experiment. And no one has identified a way to fully prevent ATC from generating interference into MSS terminals or MSS spacecraft."

Inmarsat believes that unless the DoD acts immediately to alert the FCC to its concerns, the FCC may authorise unprecedented relaxations to its earlier, appropriate ATC rulings. These relaxations will jeopardise the DoD's use of Inmarsat services.

We thus urge the DoD to insist that the FCC maintain the careful and considered approach to ATC adopted in its February 03 ATC Order, overturn the November 04 MSV License Order, and reject further relaxation requests until some operational experience with ATC can be obtained.

In closing...

...it is worth remembering the pronounced ambitions of MSV, in which they would wish to see ATC base stations deployed on cellular towers across the country...

Appendix C

Honeywell

WP-140

Commercial Flight Systems Group
Business and Commuter Aviation Systems Division
Honeywell Inc.
P.O. Box 29000
Phoenix, Arizona 85038-9000
602-436-8000

4 August 1994

Mr. George Cobley, SC-165 WG-1 Chairman
Rockwell International
Collins Avionics
400 Collins Road N.E.
Cedar Rapids, Iowa 52498

Dear George:

Subject: SATCOM Receiver Saturation Effects.

Ian W. Philpott sent me a copy of an analysis of saturation effects in receivers which he has written. This analysis brings to light an aspect of interference to the SATCOM AES receiver that has not been explored in earlier analysis of this system. The following is a more extensive theoretical analysis which hopefully will add to the effort started by Ian.

As Ian points out, the non-linearities of a system can be represented by an infinite power series (using notations specific to an RF receiver)

$$V_{out} = \sum_{n=1}^{\infty} k_n V_{in}^{\,n} \tag{1}$$

As Ian further points out, the power series is commonly truncated after the third-order term, i.e.,

$$V_{out} = k_1 V_{in} + k_2 V_{in}^{\,2} + k_3 V_{in}^{\,3} \tag{2}$$

Amplifier Characterization

For the situation under consideration in this case one has a sinusoidal input voltage in a 50 ohm system such that

$$V_{in} = A\cos(\omega_o t) \qquad (3)$$

Then, squaring and cubing V_{in} and applying some trigonometric identities, one arrives at the following:

$$V_{in}^2 = A^2\cos^2(\omega_o t) = 0.5\,A^2[1 + \cos(2\omega_o t)] \qquad (4)$$

$$V_{in}^3 = A^3\cos^3(\omega_o t) = 0.5\,A^3[1 + \cos(2\omega_o t)]\cos(\omega_o t)$$

$$= 0.75\,A^3\cos(\omega_o t) + 0.25\,A^3\cos(3\omega_o t) \qquad (5)$$

Inserting equations (3), (4), and (5) into equation (2) yields

$$V_{out} = 0.5\,k_2\,A^2 + A\,k_1\cos(\omega_o t) + 0.75\,k_3\,A^3\cos(\omega_o t)$$

$$+ 0.5\,k_2\,A^2\cos(2\omega_o t)] + 0.25\,k_3\,A^3\cos(3\omega_o t) \qquad (6)$$

V_{out} includes a DC term, fundamental terms, and second and third harmonic terms. The fundamental terms are the terms of interest in a study of saturation (i.e., compression). Therefore, the fundamental terms to consider are

$$V'_{out} = A\,k_1\cos(\omega_o t) + 0.75\,k_3\,A^3\cos(\omega_o t)$$

$$= A\,k_1\,[1 + 0.75\,(k_3/k_1)\,A^2]\cos(\omega_o t) \qquad (7)$$

The linear small-signal voltage gain is k_1. This analysis shows that when the third-power term of the non-linear equation is included, as it is in this analysis, the voltage gain of the system is modified by the term

$$[1 + 0.75\,(k_3/k_1)\,A^2] \qquad (8)$$

which is dependent on the amplitude, A, of the signal passing through the system. If k_3/k_1 has a negative real value, then the gain becomes compressed (reduced) as the amplitude reaches sufficiently large proportion such that $[0.75\,(k_3/k_1)\,A^2]$ becomes significant compared to unity.

A common characterization point used for an amplifier is its 1 dB compression point, i.e., the amplitude at which its gain has been reduced by one dB. In that case the voltage gain has been reduced by a factor of 0.89125 (i.e., $20\,\mathrm{Log}_{10}\{0.89125\} = -1$ dB). Under this condition one has

$$[1 + 0.75\ (k_3/k_1)\ A^2] = 0.89125 \tag{9}$$

and

$$k_3 = k_1[0.89125 - 1]/[0.75\ A^2] \tag{10}$$

In a case where the amplifier has a small signal, unsaturated gain of 60 dB, the fundamental coefficient is $k_1 = 10^3$ (assuming positive real voltage gain, i.e., phase shift is not a significant factor in this study).

Furthermore, if the 1 dB compression point is at +10 dBm output in a 50 ohm system (in fact, assume both the input and the output ports are 50 ohms), then the amplifier gain has reduced to 59 dB and the corresponding input power is -49 dBm ($1.259*10^{-8}$ Watts). Thus, the input amplitude can be calculated as follows:

$$P_{in} = 1.259*10^{-8}\ \text{Watts} = (A/\sqrt{2})^2/50$$

$$A = \sqrt{100\ P_{in}} = 1.122*10^{-3}\ \ V_{pk} \tag{11}$$

Note that A is peak amplitude voltage (not RMS voltage).

Applying these values of k_1 and A in equation (10) one finds that

$$k_3 = -1.1517*10^8 \tag{12}$$

Gain Compression of a Small Signal by a Large Interfering Signal

As shown in Reference 1 in Ian Philpott's paper, the small signal compression, g_c, is related to the large signal compression, g'_c, as follows:

$$g_c = 2g'_c - 1 \tag{13}$$

Both g_c and g'_c are voltage ratios. Thus, at a 1 dB compression point $g'_c = 0.89125$, as stated earlier (see equation 9).

Ian's paper uses a signal-to-noise ratio (C/N) degradation equivalent to a 1 Kelvin increase in noise temperature as a limit for small signal gain compression. As noted in Ian's paper, the system noise temperature under which the MOPS tests are specified is 451 K. A 1 Kelvin increase in noise temperature would bring the noise temperature up to 452 K. C/N is a power ratio wherein N = kTB where k is Boltzmann's constant, T is noise temperature in Kelvins, and B is system bandwidth in Hertz. Thus, the degradation in C/N can be expressed as 10 $\mathrm{Log}_{10}(T_2/T_1)$. In this case

$$10\ \mathrm{Log}_{10}(452/451) = 0.0096\ \mathrm{dB} \tag{14}$$

The relative change in C/N is $\Delta T/T_1 = 1/451 = 0.00222$ (in numeric value, not in dB).

When considering a compression of the carrier rather than an increase in the noise, the equivalent compression is 0.0096 dB and the resulting small signal compression voltage ratio is

$$g_c = 10^{0.0096/20} = 0.99889 \tag{15}$$

Then the large signal compression is, from a rearrangement of equation (13) is

$$g'_c = (g_c + 1)/2 = 0.99945 \tag{16}$$

From equation (7)

$$g'_c = V'_{out}/(A\ k_1) = [1 + 0.75\ (k_3/k_1)\ A^2] \tag{17}$$

The interfering signal level at which the C/N of a small signal degrades equivalent to a noise temperature increase of one Kelvin is, with the values of g'_c, k_1, and k_3 as outlined above,

$$A = \sqrt{k_1[g'_c - 1]/[0.75\ k_3]} = 7.98 \ast 10^{-5}\ V_{pk} \tag{18}$$

$$P = (A/\sqrt{2})^2/50 = 6.37 \ast 10^{-11}\ \mathrm{Watts} = -72.0\ \mathrm{dBm} \tag{19}$$

A similar analysis indicates that an interfering large signal at -60 dBm at the amplifier input will degrade the C/N ratio by an amount equivalent to a noise temperature increase of 16 Kelvins which produces a C/N degradation of 0.15 dB.

Receive Image and Spurious Responses

Gain compression is not the only concern to be addressed in receiver designs and specifications. Images and other spurious responses may also degrade receiver performance. If the band-edge and in-band interference specifications are set at -72 dBm as suggested above, then the image/spurious rejection for a 600 bps data channel, for example, becomes 140.2 - 72 = 68.2 dB for the in-band and band-edge cases. This appears to be quite a sensible and adequate requirement.

Conclusions

The assumptions previously used in arriving at interference levels for the SATCOM AES receiving system have not taken this type of signal quality degradation into account. For the in-band interference and the out-of-band interference close to the AES receive band edges, the considerations outlined above appear to be significant. Furthermore, the primary rejection of out-of-band interference has been attributed to the diplexer receive-band filter. Far from the receive band where there may be very large signals (TV or Radar), however, there can be additional filtering applied in the RFU. It seems that the test levels recommended in Ian Philpott's paper may be good choices for the far out-of-band interference, but that the test levels for in-band and the near out-of-band interference should be reduced to the order of -72 dBm.

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